

3D Numerical Realization of FRP Microstructure from High-Res X-Ray CT

Completed Technology Project (2014 - 2016)



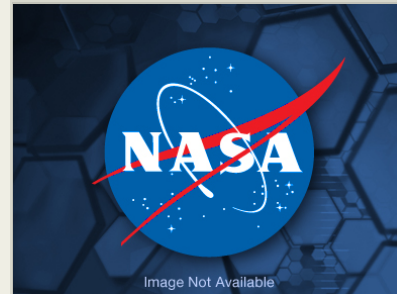
Project Introduction

Invention, deployment, and improvements in safety and reliability of next-generation composite materials and structures will require significant advances in characterization, simulation, and overall understanding of failure at constituent-level length scales. Reliance on surface-based observations, oversimplification of numerical simulations, and continued dependence on empiricism severely hinders our ability to design and deploy future, innovative, composite materials and to fully realize revolutionary, structural-prognosis concepts like the Digital Twin. The objective of the proposed work is to initiate the realization of the Digital Twin concept for fiber-reinforced polymer (FRP) composites by coupling state-of-the-art, nondestructive characterization techniques with three-dimensional, numerical modeling to study their constituent-level deformation and failure.

Currently, characterization of constituent-level failure in state-of-the-art FRP composites is limited to two-dimensional observations (e.g. using optical or scanning-electron microscopy) often using post-mortem, destructive methods. Additionally, simulation of FRP deformation and failure at the constituent-level has been either homogenized or two-dimensionalized due to the perceived computational resources needed to perform three-dimensional finite-element (FE) analyses. In contrast, for metallic alloys, recent advances in high-energy X-ray diffraction microscopy, X-ray computed tomography (CT), and supercomputing have enabled detailed characterization and simulation of deformation and failure at the grain-level scale.

For FRP composites, volumetric imaging and numerical modeling of the constituent-level microstructure provides a unique set of challenges. For instance, in order to resolve accurately the shape and location of individual constituents (e.g. fibers), volumetric imaging must be performed at a sub-micron resolution. To date, a number of researchers have reported imaging FRPs using micro-focus or synchrotron source radiation X-ray CT; however, these techniques are currently limited to a 1-2 μm resolution. Additionally, in order to simulate accurately the deformation and failure of FRP composites within a numerical framework, thousands of individual, randomly distributed fibers and the surrounding resin must be represented within a single three-dimensional model. Development and implementation of these models will require tremendous computational power, and their performance will be evaluated using novel, constituent-level characterization and validation experiments.

A recent survey of commercially available reconstruction codes highlighted the need for development of new software intended specifically for FRP composites. The new software will be based on novel pattern-recognition algorithms to extract two-dimensional spatial distribution of individual constituents, and will utilize multi-particle tracking algorithms to determine their shape in the third dimension. When completed, the new software will automatically generate realistic FE models based on real CT-derived data; or



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Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Langley Research Center (LaRC)

Responsible Program:

Center Independent Research & Development: LaRC IRAD

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alternatively, the software will collect and generate extensive statistical information to create synthetic counterparts.

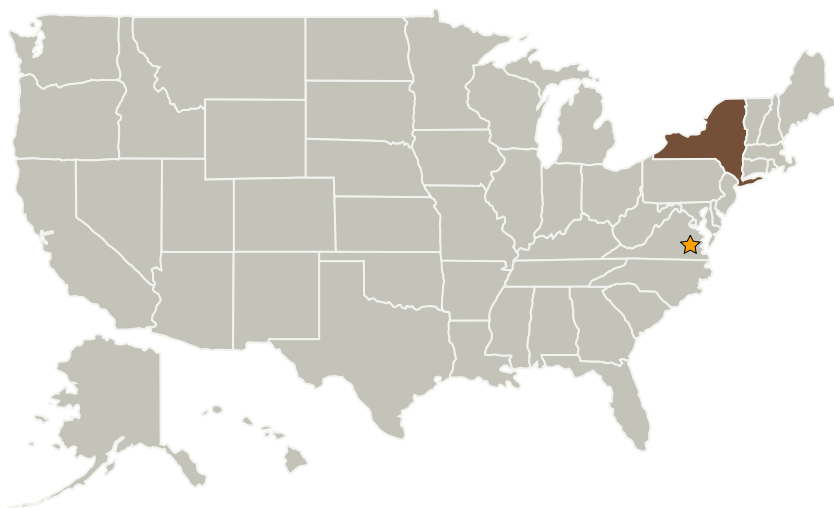
The accuracy of the realistic or synthetic FE models will be evaluated with 4D in-situ constituent-level characterization and validation experiments. These experiments will be integrated with the X-ray CT microscope chamber and will enable remote sensing of the applied load or displacement, with a concurrent unobstructed rotation of the test specimen necessary for tomographic imaging.

Anticipated Benefits

Near Term: High resolution characterization, reconstruction, and finite element discretization of fiber-reinforced polymer composite structures.

Long Term: Design of innovative composites by virtual testing and on the incorporation of composites.

Primary U.S. Work Locations and Key Partners



| Organizations Performing Work | Role | Type | Location |
|----------------------------------|-------------------|-------------|-------------------|
| ★ Langley Research Center (LaRC) | Lead Organization | NASA Center | Hampton, Virginia |

Project Management

Program Manager:

Julie A Williams-byrd

Project Manager:

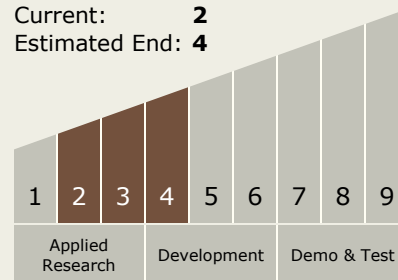
Michael W Czabaj

Principal Investigator:

Michael W Czabaj

Technology Maturity (TRL)

Start: **3**
 Current: **2**
 Estimated End: **4**



Technology Areas

Primary:

- TX04 Robotic Systems
 - TX04.2 Mobility
 - TX04.2.2 Above-Surface Mobility

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| Co-Funding Partners | Type | Location |
|---------------------|----------|------------------|
| Cornell University | Academia | Ithaca, New York |

| Primary U.S. Work Locations |
|-----------------------------|
| New York |